

Session 6 Panel Discussion

Panel Lead: J. O. Arnold (UC Santa Cruz)
Co-leads E. Kolawa (JPL) and L.Y. Del Castillo (JPL)

Question posed to Panelists: Based on your experience, what engineering instrumentation should be incorporated in future planetary atmospheric entry probes?

Richard Powell (Langley Research Center)
From the perspective of Guidance, Navigation and Control:

Why:

1. Forensic reconstruction of unexpected behavior.
Example: MER flight angle of attack profile did not match simulation.
2. Risk reduction for follow-on probes.
Example: Mars Pathfinder reconstruction demonstrated that CFD had accurately predicted high Mach bounded pitch instability.
3. Scientific experiments
Example: Proper instrumentation will allow determination of aerodynamics, parachute dynamics (e.g.; inflation behavior), atmospheric density and winds.

History:

1. Human spaceflight vehicles are well instrumented, e. g, Space Shuttle Columbia.
2. Robotic spacecraft, in general, have little or none instrumentation devoted for flight mechanics evaluation – engineers forced to use instrumentation that is primarily designed for another purpose.

Future:

1. Probes are getting more complicated – active control systems, active guidance, higher aerodynamic performance, etc. – accurate reconstruction of flight with current philosophy for minimal instrumentation will be impossible.

What is needed?

1. High data rates – large amount of information is lost between the sampling cycles.
2. High quality accelerometers and gyros.
3. Independent air data system (ex. Shuttle SEADS experiment).
4. Instrumentation tailored to specific vehicle characteristics:
Example: camera looking at parachute inflation.
Example: instrumentation to measure stresses/strains/deformation/heating/etc. for inflatables.

Michael Wright (NASA Ames)
From the perspective of Thermal Protection Systems (TPS)

We need accelerometer and pressure data, not only for vehicle orientation, but also to secure benchmarks for CFD code validation/calibration. For validation of our CFD

and TPS materials thermal response models, we need heating rates as well as temporal recording of temperatures both at the surface and in depth. In severe environments where ablation occurs, recession sensors are very important, e.g. on the Galileo probe. At higher velocities and for bodies with a large nose radius, shock layer radiation is an important component of the heating, and our understanding is not good, e.g. for the Huygens probe. It would be good to have a spectrometer on appropriate entries if at all possible to help solve this issue.

Why do we care? Understanding the uncertainty – without understanding uncertainty we cannot know system risks. If a mission fails because of heat shield design that would be very good to know. If we detect near failure events, we would have less failures and this is critical from the perspective of the future missions within exploration programs. Modeling is much less expensive than testing (especially flight testing), but one cannot reliably use the models outside of the area tested. The data are needed not necessarily to reduce TPS mass but **much more importantly to understand uncertainty and to reduce system-level mission risks!**

Jean-Marie Muylaert (ESA/ESTEC, Netherlands)
From the European perspective of Aerothermodynamics and TPS

We need flight data to improve our future designs. I was particularly impressed by Ames' presentation in this session regarding instrumentation. We wish to share ESA activities designed to improve tools to understand transition to turbulence and shock interactions based on flight measurements. We must heed the lessons learned from non-repeatability of Huygens. At this point, we don't believe what we measure, for example we do not know how to embed gauges in TPS which leads to the falsification problem. We don't need to measure temperature in the boundary layer, because it's not giving us a true value. We need to know the real physical parameter. We will have to fly capsules in test beds to understand the underlying physics. We must strive to improve design issues. This drives us to consider things like high temperature windows, electron beam probes and fly them in test beds. We would like to share with you the expertise we plan to develop. This international probe community, comprised of government, industry and universities is the perfect embodiment for future flight research programs to develop the tools we need for future designs. Some problems can be inexpensively solved by in-flight research programs, e.g., the shock layer radiation problem for Huygens. Design of flight experiments can bridge the gap. I believe we can really do it now and not wait 40 years. We need to focus on securing flight experiment data. Aerodynamicists do not work enough with different technology like MEMS and they should strive to do so. We need to perfect our community to develop deep understanding of issues facing probe design.

Bobby Kazeminjad (Space Research Institute, Austrian Academy of Sciences, Austria). From the perspective of atmospheric science:

The top of my list wish is a significant increase of data rate. There are considerable differences in the orbiter contrasted with the probe. From our experience, the Huygens probe mission was very constrained by data rate. Given the limited time, we could have secured so much more science and images with better communications. Increased sampling rates would allow us to send more information in same time

frame. Miniaturization: we see a lot of effort being put into this field. With limited mass budget, smaller devices with capabilities comparable to today's packages translates to more instruments and more variety of measurements, speeding us along the scientific and engineering learning curves and data sets. If we increase the mass and data rate, both learning curves are more extensive. As pioneered by Al Seiff, in the early atmospheric structure experiments, engineering and science data provide a very nice cooperation. An example is ablation sensors which were necessary to understand changes in the vehicle's mass and ballistic coefficient in order to do the atmospheric reconstruction. These data help understand TPS performance as we have seen. So, it is really incorrect to label instrumentation solely as "engineering", and this point needs to be made to scientists and mission managers when marketing flight instrumentation.

Harry Partridge (NASA Ames Research Center). From the perspective of emerging nanotechnologies:

Currently, there is considerable worldwide interest in the emerging field of nanotechnology as evidenced by the worldwide investment of \$ 4 B/year. Research is showing the remarkable value of nanotechnology for materials and sensors. In nanomaterials, for example, strength increases as does the modulus. Over the decade, materials are expected to become available with 5X the specific strength (i.e. strength-to-weight ratio); and by 2020 nano-scale materials could result in up to a 50 percent weight savings in spacecraft and aircraft structures as well as thermal protection systems for atmospheric entry. By controlling nano materials, one can develop sensors with extreme sensitivity and selectivity and increased fault tolerance. By interfacing with MEMS type devices, considerable increases in capability should be achievable. Some nanotechnologies are further developed than others. For example, a carbon nanotube electron emitter is on the market. There are many sensor system arrays that are very adaptable and some are not very far away from space flight demonstrations.

Questions and comments from the audience and panel members:

Ed Martinez (NASA Ames): Once we see the atmospheric structure profiles of Titan's atmosphere, a lot of interpretation will be forthcoming. It would be good to be able to say that the density profiles for Titan from Huygens took into account the loss of probe mass. There is double-sided interest in ablation sensors. Large mass losses were expected for the Galileo probe for the Jovian entry, and that's why ablation sensors were flown. Change of TPS shape is important because it affects the drag coefficient. Both of these factors must be taken into account for atmospheric reconstruction. Uncertainty analysis is not good enough. Communication is important--wireless sensors should be distributed on TPS--nobody wants wires. Unfortunately, on the other hand, depending on mission, embedding sensors in TPS is perceived to increase mission risk.

Tom Spilker (JPL): Regarding communication in entry phase: It is not possible to communicate during entry phase using electromagnetic media from through the plasma sheath during the high speed portion of the entry - another option is a black box to communicate data later.

Jean-Marie Muylaert (ESA/ESTEC): Depending on type of TPS used, it may make sensors more challenging - is this reason for reluctance? If you look back far enough in time, probes for Earth entry were loaded with pressure ports, temperature, etc. enough time has past that we will have to do it again.

Dan Reda (NASA Ames): Based on years of experience, I strongly concur with the points made that can retire risk in the design of heat shields. This is especially true in those instances where transition to turbulent flow can lead to over-design.

Raj Venkatapathy (NASA Ames): What we are suffering from is the “faster better cheaper problem”- We have been using the same TPS material for Mars entry since Viking and still do not have the material completely characterized. We need to understand this risk factor. Hopefully we can get things that are needed not only for this mission (project) but also for a whole series of missions (program).

Jim Arnold (UC Santa Cruz): Looking through windows during the high speed entry stage is a very tough problem as we learned during the not-flown Aeroassist Flight (10 km/sec), although it has been done at lower speeds, e.g. the PAET radiometer experiment. Shock layer radiation experiments are hard at high speeds. Doing a window in a heat shield is a very tough problem. On Apollo 4, a radiometer looked through a window in the bottom of a cavity in the heat shield, but ablation deposits compromised the data. That in itself is a challenge, and need work on this as we look forward to the CEV development.

Ralph Lorenz (Univ. of Arizona) Payload mass fraction is not improving. There is obviously a demand to increase payload mass fractions for atmospheric entry probes: Has anyone look at COTS for robust communication between devices? It appears that each PI treats their instrument as a discrete problem and this leads to packaging problems - Beagle had a 38 percent payload mass fraction and perhaps we could do better. Is anyone looking outside our own fields into system integration? The panel lead directed this question to Jim Cutts/JPL, knowing that his lab is looking at new technology and getting it into space systems-radiation effects on next generation electronics, etc. Cutts referred this to Elizabeth Kowala.

Elizabeth Kowala (JPL): Depending on what kind of electronics, there are different issues. For example, looking at electronics for Europa missions - non-volatile memories present a problem. There is a large investment in commercial world in non-radiation hard data storage, but radiation-hard, high-density data storage for Europa missions is not yet available. A similar situation exists for high temperature electronics for Venus missions. There is no commercial market for 500 C electronics, so their development must be paid for by NASA. Electronics able to operate in Mars environment: could be developed. Many Silicon CMOS devices will operate in the range of -120 to +20 C and packaging able to withstand thermal cycling on Mars is feasible. However, extending qualification beyond catalog data (which relies on military standards) is really a large issue. We really do not know how to do this properly.

Harry Partridge (NASA Ames) The electronics industry is clearly facing significant challenges in extension of CMOS in the period around 2015 to 2220 going below 15 nm feature sizes. Many believe that some sort of nanotechnology will break this

barrier. Projected fault range for nanodevices is thought to be about 90 percent in the manufacturing of networks. This calls for fault tolerant architectures, like those being explored by HP. These will more amenable to reliable operation the space radiation environment.

Final comment (unknown): The payload mass fraction of Beagle 2 is impressively high and this is true for the Mars Polar Lander high as well. Everyone tends to bring their own box and asking how big is my box? We need to look at volume and packing density of instruments.

Summary: There seems to be agreement that additional flight instrumentation needs to be flown on future probes and that dedicated flight experiments to retire risk for future missions would be very valuable. It is believed that this topic be one several of the strong consensus points to be made as the IPPW moves forward to exercise influence on decision makers as suggested by Ames Director Hubbard in the wrap-up session of the IPPW #3.

